The American Association of Petroleum Geologists Bulletin
V. 74, No. 7 (July 1990), P. 1030-1037, 4 Figs., 1 Table

Subsurface Structure of the Eastern Arkoma Basin[1]

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ABSTRACT

Analysis of 425 km of seismic reflection data in the eastern Arkoma basin reveals a structure and history quite different from those previously reported for the Arkoma basin. The eastern Arkoma basin has three structural styles that formed in the following chronological order: deep, steep normal faults; shallow listric normal faults; and thrust faults. The origin of the structural styles and the Paleozoic history of the eastern Arkoma basin may be summarized as follows. Late Proterozoic or Early Cambrian rifting was followed by deposition of Cambrian through Upper Mississippian strata on a passive plate margin. The Mississippian–Pennsylvanian boundary marks a time of major down-to-the-south normal faulting with coincident folding of the footwall blocks and truncation of the faulted and folded terrain by a pre-Morrowan (Mississippian–Pennsylvanian) unconformity. The unconformity slopes southward and steepens locally across the erosionally truncated footwall blocks. During the Pennsylvanian, down-to-the-south listric normal faults cut the Atokan and Morrowan sections and merged with, but did not displace, the steeper segments of the sub-Morrowan unconformity. Surface folds north of the Ross Creek thrust are rollover anticlines overlying these listric normal faults. Major deformation in the eastern Arkoma basin terminated with emplacement of the Ross Creek thrust in the Late Pennsylvanian.

INTRODUCTION

The Arkoma basin is a foredeep basin extending from central Oklahoma to eastern Arkansas and is bounded by the northeast Oklahoma platform and Ozark uplift on the north and the Ouachita Mountains on the south (Figure 1). Most of the Arkoma basin literature describes the western part of the basin in Oklahoma and western Arkansas. These previous workers have reported that from the Early Cambrian through Early Pennsylvanian, the area of the future Arkoma basin was part of a broad continental shelf along a passive continental margin bounded by the Ouachita trough on the south (Houseknecht, 1986; Sutherland, 1988). Continental convergence began in the middle Mississippian, ultimately resulting in the conversion of the shelf into a foredeep basin in the middle Atokan (Middle Pennsylvanian) (Houseknecht, 1986; Sutherland, 1988). Also during the middle Atokan, large down-to-the-south growth faults were active in the Arkoma basin. These growth faults have been reported as steep faults that displace the entire section from the Precambrian through the middle Atokan (Buchanan and Johnson, 1968; Haley, 1968; Zachry and Sutherland, 1984; Denison, 1989). Deformation in the Arkoma basin culminated in the Late Pennsylvanian with thrusting of the Ouachita orogeny (Keller and Cebull, 1973; Wickham et al., 1976; Lillie et al., 1983; Denison, 1989).

East–west-trending, box-shaped synclines and narrow anticlines are the dominant surface structures of the Arkoma basin (Buchanan and Johnson, 1968; Viele, 1973). In the western Arkoma basin, thrust faults are exposed in the crests of many anticlines and are reported to underlie the folds (Viele, 1973; Blythe et al., 1988). Furthermore, the thrust faults displace the upper Atoka strata and are believed to have displaced or reactivated some of the older growth faults (Buchanan and Johnson, 1968; Viele, 1973; Blythe et al., 1988).

With the exception of Haley et al. (1976) and Viele (1979), very little has been published on the structure of the eastern part of the Arkoma basin in Arkansas. However, a cursory examination of the state geologic map of Arkansas (Haley et al., 1976) reveals that faults in the eastern part of the basin strike northeast, whereas in western Arkansas they strike due east. This difference in fault strike suggests that there may be significant differences between the structure and history of the eastern and western Arkoma basin.

To better understand the structure of the eastern Arkoma basin, we undertook an analysis of 425 km of migrated seismic reflection profiles over a 1950-km^2 area of central Arkansas (Figures 1, 2). From this analysis, we conclude that there are significant differences between the published subsurface structure and history reported in the western Arkoma basin and that which we document in the eastern Arkoma basin.

[1]Manuscript received, July 20, 1989; revised manuscript received, March 9, 1990; final acceptance, April 16, 1990.

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We thank the Arkansas Science and Technology Authority (Basic Research Grant 86-B-0082) for its financial support. We also are greatly indebted to our friends in the petroleum industry who provided the seismic data. Helpful discussions and reviews were provided by Tom Heinecke, Walter Manger, Lisa Kanter, David Houseknecht, David Bieler, William Thomas, and Dave Reeves.

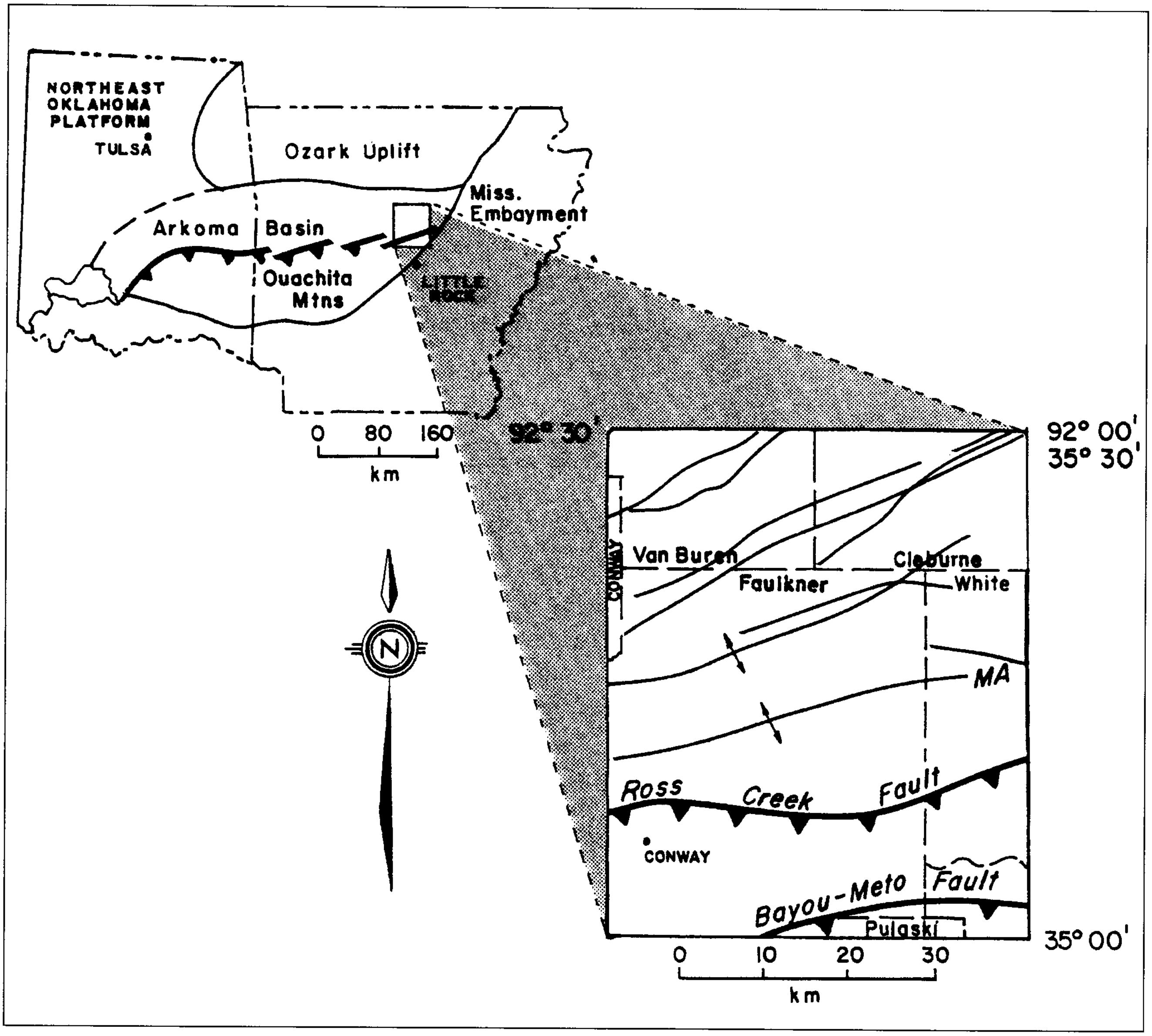


Figure 1—The study area in the eastern Arkoma basin north of Little Rock, Arkansas. Unlabeled thin lines on inset map are normal faults. MA = Morrilton anticline.

STRATIGRAPHY OF THE EASTERN ARKOMA BASIN

Control for the stratigraphic interpretation of the seismic data is provided by eight gas wells in the area (Table 1), five of which are located on or near line AA' (Figures 2, 4). A stratigraphic column for the eastern Arkoma basin is illustrated in Figure 3. Some of the nomenclature from Oklahoma (e.g., the Arbuckle Group) has been continued here because of the widespread use of these names in the Arkoma basin by the petroleum industry. The stratigraphy of the eastern Arkoma basin consists of the Pennsylvanian Atoka Formation (sandstones and shales), the Pennsylvanian Morrowan Series (sandstones and shales), the Upper Mississippian Pitkin through Moorefield formations (limestones, shales, and sandstones), the Lower Mississippian Boone Formation (limestone and chert), and a dominantly carbonate Devonian–Cambrian section. The reader is referred to the following papers for more detailed descriptions of the stratigraphy of the eastern Arkoma basin: Croneis (1930), Maher and Lantz (1953), Caplan (1954), Frezon and Glick (1959), Stone (1968), Sutherland and Manger (1979), and Houseknecht (1989).

The Arco Exploration 1 Wayne Edgmon well was drilled to 12,120 ft (3694 m) (Figure 4) and terminated in Precambrian diabase and granite (Dension, 1984). Numerous continuous reflectors of unknown origin are evident below the bottom of the 1 Wayne Edgmon well with one prominent seismic reflector (labeled Pc on Figure 4) sloping southwestward beneath the entire study area.

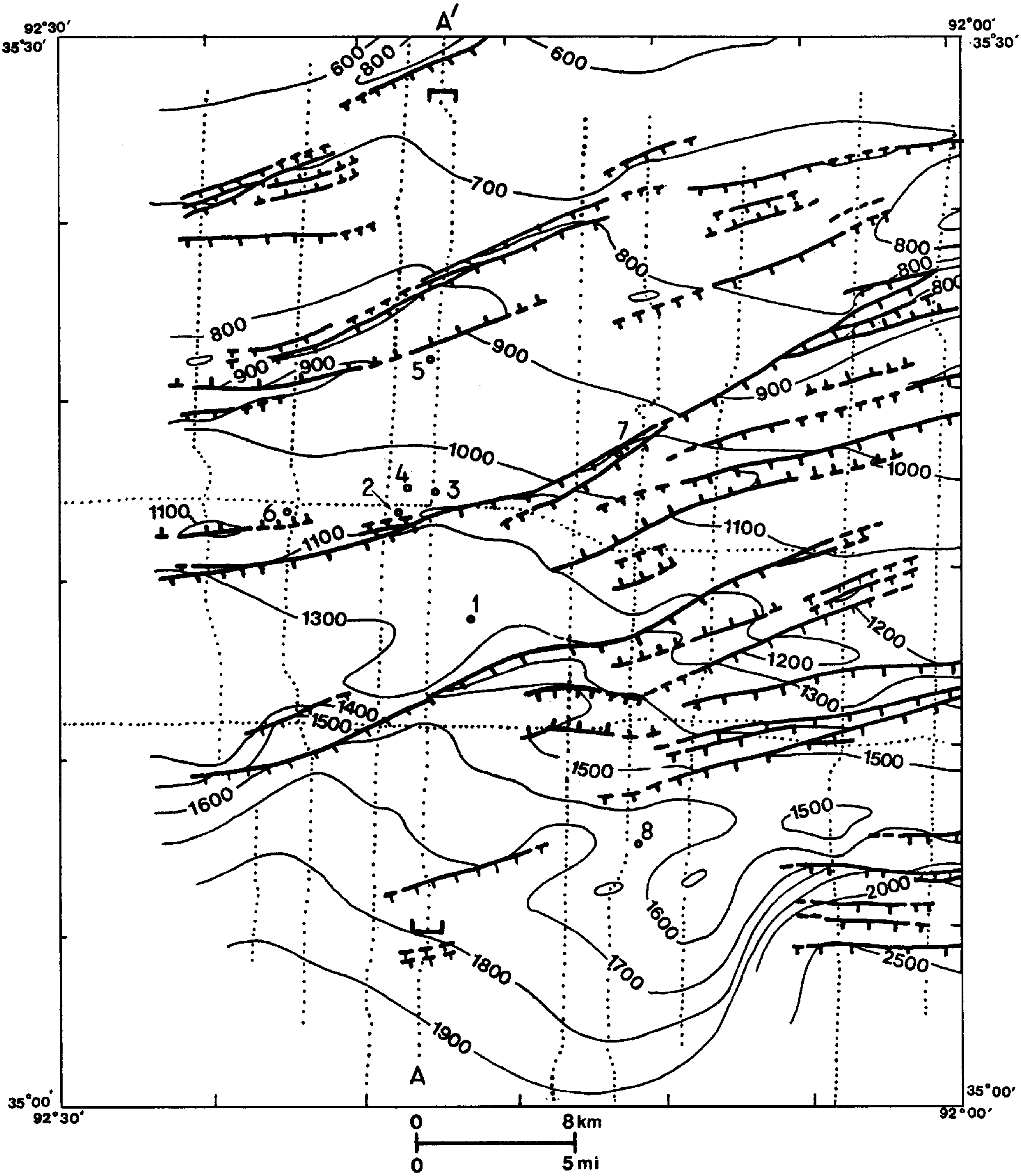


Figure 2—Two-way traveltime structure map of the Boone Formation (reflector B in Figure 4). Contours in msec. Bold lines are normal faults, barbs on downthrown side. Dotted lines are the locations of the seismic reflection lines used in this study; the brackets indicate the part of line AA' shown in Figure 4. Numbered points are the following gas exploration wells: 1 = Lone Star 1 E.W. Moore Estate, 2 = Arco Exploration 1 Wayne L. Edgmon, 3 = Santa Fe Energy 1-29 Mary Lou, 4 = Stephens Production 1 S.A. Hovis, 5 = Sepco 1-8B Brown, 6 = Santa Fe Energy 1-4 Sowash, 7 = Diamond Shamrock 1 Rushing, 8 = Shell Oil 1-28 Atkinson.

Table 1. Depths to Tops of Units in Gas Exploration Wells*

Tops	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
Areci	1287	588	+215		+201	295		
Frieburg	1887	1000	318		209	984		
Sells	2807	2251	1406		1221	1913	1210	3480
Basal Atoka	3649	3032	2135	2047	1857	2761	1709	4090
Bloyd	3947	3340	2468	2322	2233	3104	2097	4421
Hale	4338	4100	3325	3129	2645	3729	2608	
Pitkin	6117	NP	4348		4033	4949		
Batesville	6792	5542	4988		4575			
Boone	7547	5800			5133			
Chattanooga	7632	5930			5235			
Sylamore	7727	6092			5394			
Ordovician	7872	6370			5695			
Total Depth	10,500	12,120	5705	4001	6394	5800	4646	6496

*Modified from Burroughs (1988). Depths are in feet below sea level. NP = not present, + = above sea level. Wells are as follows: well 1 = Lone Star 1 E. W. Moore Estate, well 2 = ARCO Exploration 1 Wayne L. Edgmon, well 3 = Santa Fe Energy 1-29 Mary Lou, well 4 = Stephens Production 1 S.A. Hovis, well 5 = Sepco 1-8B Brown, well 6 = Santa Fe Energy 1-4 Sowash, well 7 = Diamond Shamrock 1 Rushing, well 8 = Shell Oil 1-28 Atkinson.

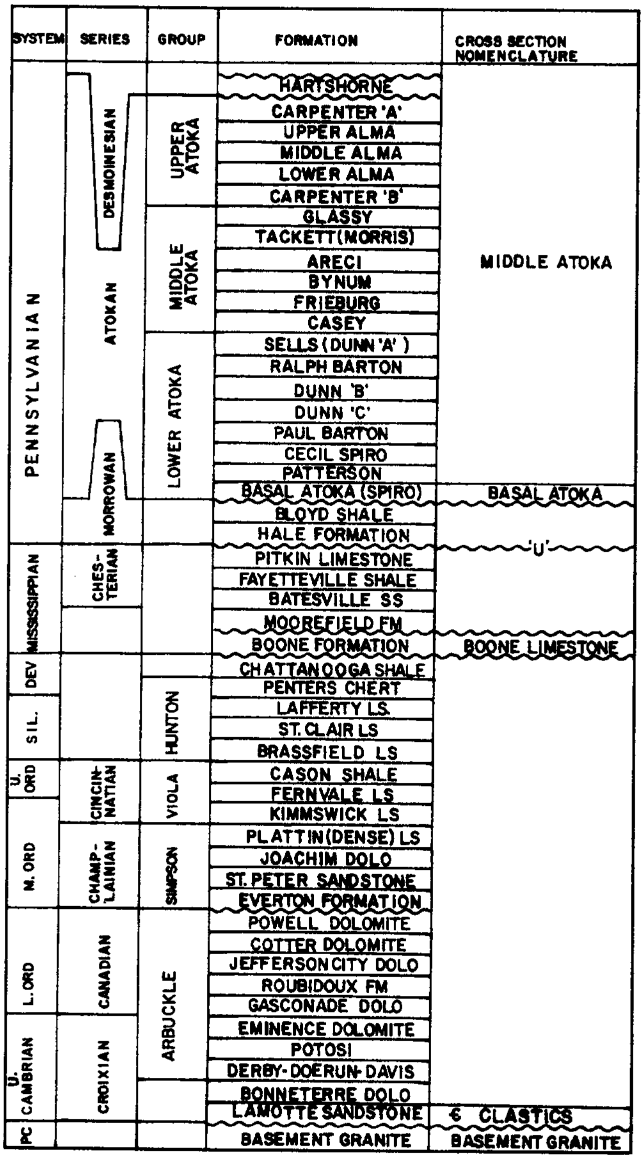


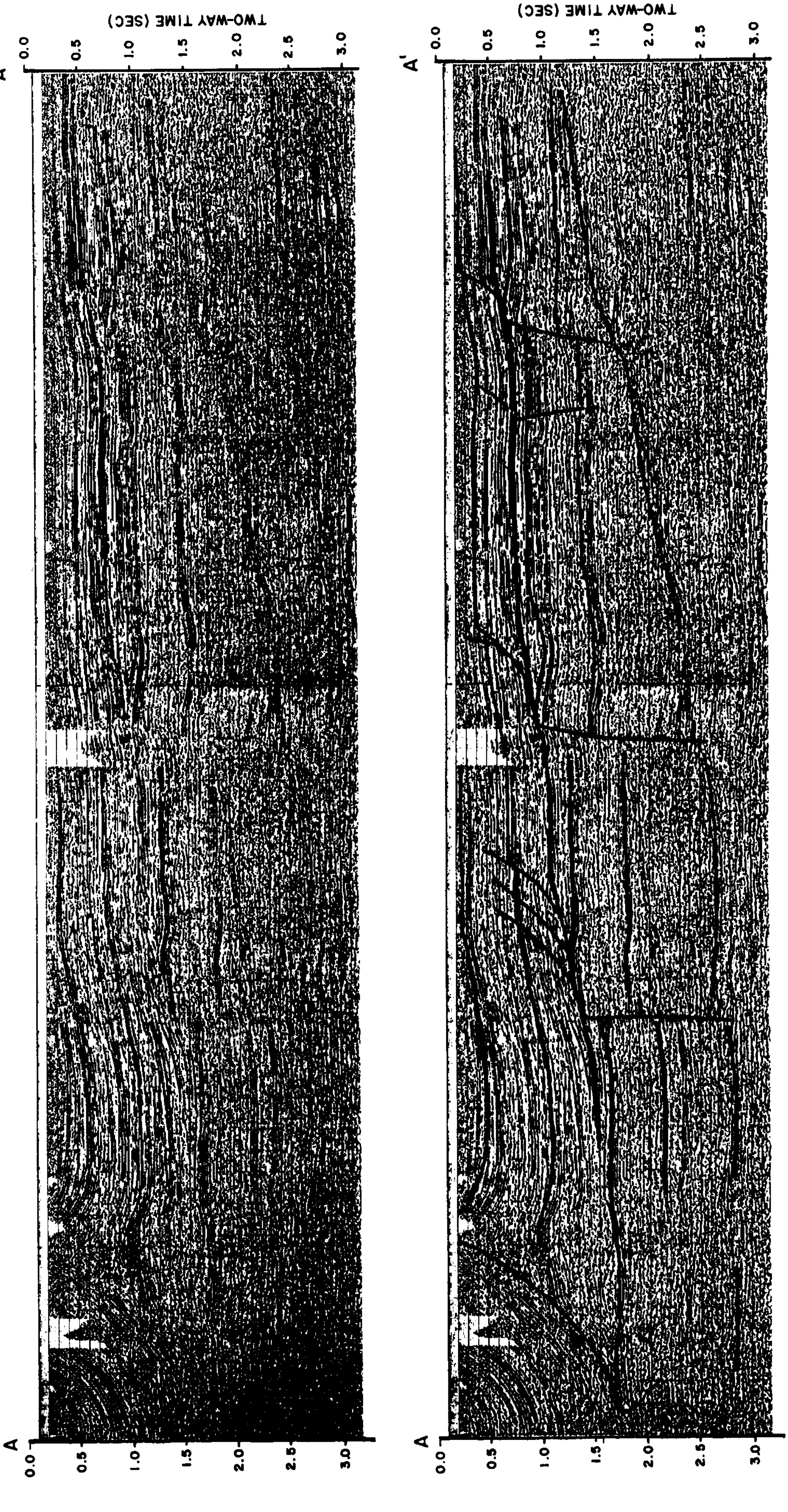
Figure 3—Stratigraphic column for the eastern Arkoma basin with a simplified column for Figure 4. Only major unconformities are shown.

STRUCTURE OF THE EASTERN ARKOMA BASIN

Surface structure of the eastern Arkoma basin consists of northeast-trending, down-to-the-southeast normal faults; a series of subhorizontal, upright, northeast-trending folds; and the Ross Creek thrust fault (Figure 1).

Two different structural regimes are evident on the seismic lines in the subsurface north of the Ross Creek thrust fault (Figure 4), a deep basement structural regime and a near-surface structural regime. Both regimes have high-angle, primarily south-dipping normal faults; however, normal faults in the near-surface regime are listric and do not continue into the deeper basement faults. The steep, deep basement faults are continuous from the Proterozoic basement (Bickford, 1988) upward through the Mississippian Pitkin Limestone and are terminated at the base of the Pennsylvanian Morrowan Series by a truncation surface. This truncation surface marks the boundary between the two structural regimes and is most evident on the seismic profiles as a truncation of reflectors across the footwall blocks of the basement faults (Figure 4).

The near-surface Morrowan and Atokan section has wide, flat-bottomed synclines, narrow anticlines, and northeast-trending listric normal faults with primarily down-to-the-southeast displacement (Figure 4). These narrow anticlines are rollover anticlines overlying the shallow listric normal faults. The listric faults have displacements ranging from 30 to 75 m; some of the faults display minor thickening in the hanging-wall blocks, indicating minor syndepositional growth. Most of these faults are located north of major basement faults and merge into the locally steeply sloping truncation surface at the base of the Morrowan. A few faults, on seismic lines not presented here, merge into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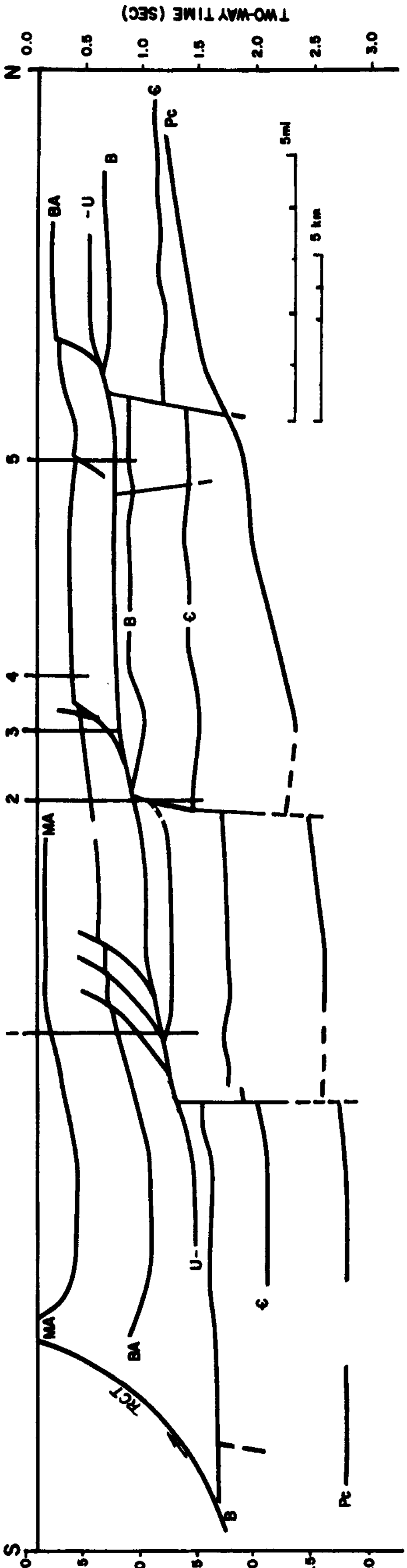

Figure 4—Migrated seismic reflection line AA' of Figure 3 and geologic interpretation. Pc = Precambrian reflector, Є = Cambrian reflector, B = Boone Formation, U = Mississippian–Pennsylvanian unconformity, BA = basal Atoka sandstone, MA = middle Atoka sandstone, RCT = Ross Creek thrust fault. Numbers 1–5 are gas exploration wells, three of which have been projected along strike into the plane of the cross section (Figure 2). Wells: 1 = Lone Star 1 Moore, 2 = Arco Exploration 1 Wayne L. Edgmon, 3 = Santa Fe Energy 1-29 Mary Lou, 4 = Stephens Production 1 S. A. Hovis, and 5 = Sepco 1-8B Brown.

the base of the Atokan section where the Atoka strata is locally steeper above the footwall blocks.

Numerous northeast-striking steep basement faults are apparent below the pre-Morrowan surface (Figures 2, 4). Individual fault strikes are generally straight but change from N50°E in the west to N70°E in the east (Figure 2). From west to east across the map area, faults with large displacements change to numerous smaller displacement faults (Figure 2). Displacement of the Boone Formation reflector across individual faults ranges from 250 to 550 m and total overall displacement across all faults from north to south is approximately 1500 m along cross section AA'. Locally, hanging-wall blocks of major normal faults contain minor horsts and grabens. The footwall blocks of the major normal faults appear to have been folded into anticlines or tilted down-to-the-north (Figure 4). This footwall deformation is evident through the deep section but is truncated at the base of the Morrowan.

We have designated the deepest traced reflector as being Precambrian because it lies 2500 m below the base of the Arco Exploration 1 Wayne L. Edgmon well (Figure 4, Table 1). The reflector descends from 3000 m below sea level in the northern end of Figure 4 to 6650 m below sea level beneath the Ross Creek thrust fault. The reflector descends less steeply from east to west across the eastern Arkoma basin and is displaced by the major south-dipping basement faults.

DISCUSSION

The structure of the eastern Arkoma basin reveals three different structural regimes: deep, steeply dipping normal faults; shallow listric normal faults; and thrust faults. Thrusting is confined to the Ross Creek thrust and southward. The seismic profiles in this study do not extend far enough south to permit interpretation about thrust faulting; however, it is evident that the Atokan listric normal faults predate the Ross Creek thrust fault because some listric normal faults (not present on the seismic line illustrated in Figure 4) underlie the Ross Creek thrust.

The shallow listric faults and associated rollover anticlines appear to be indirectly related to the deep basement faults. Most of the shallow faults are located north of basement faults and they merge with the pre-Morrowan truncation surface where the surface is locally steep. This surface slopes gently to the southwest throughout the area; however, it steepens across the folded footwall blocks of the deep basement faults (Figure 4). The listric faults are apparently controlled by the location of these bevelled footwall blocks.

The origin of the sub-Morrowan truncation surface is critical to understanding the structural evolution of the eastern Arkoma basin. This surface could be a decollement related to Ouachita thrusting or Atokan-age listric normal faulting, or it could be an erosional unconformity. We do not believe that the surface is a thrust fault because there is no evidence for thrusting north of the Ross Creek thrust fault and, indeed, all faults and folds north of the Ross Creek thrust fault are normal faults and rollover anticlines reflecting extensional deformation. The interpretation that the bevelled basement blocks are due to listric normal faulting is not feasible because the truncation surface continues up section north of the listric faults (Figure 4). The favored explanation for this sub-Morrowan surface is that it is an erosional unconformity at the Mississippian–Pennsylvanian boundary that was later activated during Atokan listric normal faulting. Our reasons for supporting this interpretation are the presence of an unconformity at the base of the Morrowan in the Arkoma basin (Sutherland and Manger, 1979; Sutherland, 1988) and that the major faulting at the close of the Mississippian, as revealed in the displacement on the Boone Formation (Figure 4), dictates that there would have been up to 550 m of structural relief across the basement faults at the close of the Mississippian, thus providing topographic relief for erosion of the footwall blocks. The footwall blocks may have been Late Mississippian submarine scarps, but more likely were subaerial mountain fronts that subsequently eroded northward from frontal faults (Lowell, 1985, p. 228-233). This latter interpretation is preferred because the close of the Mississippian was a time of very low sea level and the exposed basal Morrowan in northern Arkansas suggests subaerial deposition (Sutherland and Manger, 1979).

Footwall deformation of the deep normal faults is apparent in Figure 4; however, the geometry of the deformation is not clear. The footwall blocks appear to have been folded into an anticline and syncline, or alternatively, tilted down-to-the-north. Because the reflectors are smoothly continuous through the synclines, it appears that the footwall deformation is due to folding. Whether the deformation is folding or down-to-the-north tilting, the net result is that along strike of the basement faults there are many miles of upturned Paleozoic strata truncated by the sub-Morrowan unconformity.

The deepest traced reflector of Figure 4 is 2500 m below the crystalline rock described in the bottom of the Arco Exploration 1 Wayne L. Edgmon well. We do not know the origin of this deep reflector but it appears to lie within the Proterozoic basement.

CONCLUSIONS

The late Proterozoic and Paleozoic structural evolution of the eastern Arkoma basin interpreted from the seismic data may be summarized as follows: (1) late Proterozoic or Early Cambrian rifting (Houseknecht and Kacena, 1983; Thomas, 1985), (2) deposition of Cambrian strata through Mississippian Pitkin Limestone on a passive plate margin, (3) down-to-the-south normal faulting (Frezon and Glick, 1959) and formation of footwall anticlines in the latest Mississippian, probably due to Ouachita thrust loading south of the Arkoma basin (Houseknecht, 1986), (4) truncation of the anticlines by the pre-Morrowan (Mississippian–Pennsylvanian) unconformity, (5) deposition of the Pennsylvanian Morrowan and Atokan strata, (6) down-to-the-south listric normal faulting within the Morrowan and Atokan rocks during the Pennsylvanian, with the faults primarily soling into the steep surfaces of the pre-Morrowan unconformity, and (7) Late Pennsylvanian Ouachita orogeny thrusting and formation of the Ross Creek thrust (Arbenz, 1984; Sutherland, 1988; Denison, 1989).

Significant differences exist between the structural style and history of the eastern Arkoma basin and those reported in the literature for the western part of the basin. Most notable is the timing of the major basement faulting. Basement faulting has been reported as coincident with middle Atokan growth faulting in the western part of the basin; however, in the eastern Arkoma basin, faulting and folding of the footwall blocks is narrowly confined to the post-Pitkin (Pitkin identified in wells 1, 3, and 5 of Figure 4) and pre-Morrowan interval (at the Mississippian–Pennsylvanian boundary). Second, in the eastern Arkoma basin, the normal faults in the Atoka section do not merge with the deep basement faults as has been reported for the western basin. The shallow Atokan faults merge with locally steeper parts of the sub-Morrowan unconformity located north of the inactive deep basement faults. Thus, two distinct episodes and styles of normal faulting are found in the eastern Arkoma basin. A third difference is that narrow anticlines north of the Ross Creek thrust fault in the eastern basin (e.g., the Morrilton anticline) are not a result of tectonic shortening and have no evidence of underlying thrust faults like those reported beneath anticlines in the western Arkoma basin. The narrow anticlines of the eastern Arkoma basin are rollover anticlines overlying listric normal faults. We do not know why the structural geometry and timing differ between the eastern and western parts of the basin; however, it does appear that Carboniferous faulting may have progressed from east to west across the Arkoma basin (Graham et al., 1975; Houseknecht and Kacena, 1983). Whether the structural style and timing differences reflect a simple transition from east to west or whether there are major structural discontinuities in the Arkoma basin awaits further study.

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